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Present and future limits for the PV generation growth

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Abstract. Renewable energy sources are central issues in the current EU energy policy. According to the European Council agreement on climate and energy package of December 2008 (the “20-20-20”), by 2020 the EU is committed to reducing its emissions of greenhouse gases to at least 20% below the 1990 levels, increasing the share of renewables in the energy mix to 20% and increasing power efficiency by 20%.
Among renewables, photovoltaic (PV) is one of the most promising. Long derided as uneconomic, it is gaining ground as technologies improve and the cost of traditional energy sources rises. Also owing to the subsidies provided in different States, the PV market is quickly growing and PV technologies evolving. In some years, unsubsidized PV power could cost to end customers no more than electricity generated by fossil fuels or by renewable alternatives to solar in many markets, such as California and Italy, where an exceptional growth of PV in the next decade can be expected. This paper aims at pointing out the main factors that will limit PV penetration in the generation mix in 2020, even if PV maintains the best promises concerning cost reduction and technological and industrial development.

Keywords: PV generation, PV costs, PV technology

Sedanje in bodoče omejitve rasti deleža električne energije iz sončnih elektrarn

Povzetek. Obnovljivi viri energije so osrednji rezultat trenutne energetske politike EU. V skladu z dogovorom Evropskega sveta o klimatskem in energetskem svežnju iz decembra 2008 ("20-20-20"), se je do 2020 Evropa zavezala zmanjšanju izpustov toplogrednih plinov vsaj 20% pod nivo 1990, povečanju deleža obnovljivih virov v skupni energetski porabi na 20% in povečanju energetske učinkovitosti za 20%. Med obnovljivimi viri je fotovoltaika ena najobetavnejših. Dolgo časa zapostavljena kot neekonomična, je postala zanimiva z napredkom tehnologij in dvigom cene klasičnih energetskih virov. Zahvaljujoč subvencijam v različnih deželah trg PV hitro raste, razvija se tehnologija. Na mnogih trgih, kot sta Kalifornija ali Italija, kjer je v naslednjem desetletju pričakovati izjemno rast fotovoltaike, bi lahko v nekaj letih stala končnega odjemalca nesubvencionirana električna energija iz sončnih elektrarn toliko, kot tista, pridobljena iz fosilnih goriv ali drugih obnovljivih virov.

V članku želimo poudariti glavne dejavnike, ki bodo omejevali prodiranje fotovoltaike v energijski mešanici 2020, čeprav ta izkazuje najboljše možnosti zmanjšanja stroškov ter tehnološkega in industrijskega razvoja.

Ključne besede: raba sončne energije, stroški, tehnologija

1 Introduction

Solar energy has several remarkable advantages: it is free, plentiful (by much higher than the world energy consumption), inexhaustible, easily accessible and distributed (and abundant in many depressed areas of the world), clean (in the sense that it is used by devices which operate with practically zero-emissions).

On the other hand, the drawbacks of solar energy are low density and discontinuous and uncertain availability (due to day/night alternation and weather changes, respectively). The low density causes a gap between its potentiality and its real exploitation possibility, whereas low availability leads to a low load factor of PV plants (annual energy produced / annual energy corresponding to the installed power): at our latitudes, 1/6÷1/8.

In addition, PV energy is not yet economically competitive. A widespread economic parameter to compare the various sources for electricity generation is the “Levelised Electricity Cost” (LEC) or, more simply, “mean production cost”, defined as:

$$LEC = (C_I * A + C_o) / E \tag{1}$$

where C_I is the investment cost of the power plant, C_o the mean annual O&M cost, E the annual energy produced, and A the actualization coefficient:

$$A = r / (1 – (1 + r)^{-N}) \tag{2}$$

which depends on the service life of the plant (N, in years) and on the rate of interest r. Just for example, if r = 5% and N = 20, A ≅ 0.08.

Since the LEC depends on many factors, it must be handled with care: depending on the values used for

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calculation, the LEC can change in a quite wide range. For example, the costs of a given plant (or technology) should concern the whole life cycle of the plant, including also its final “decommissioning”, but often this final stage is not properly estimated.

Today, the PV LEC in Italy is in the range 0.30-0.40 €/kWh, roughly five times the LEC of many fossil-fueled power plants and two times the electricity price for the end customers (close to 0.17 €/kWh [1]). The high PV LEC is mainly due to still too high investment costs, whereas the O&M costs are quite limited, about 1-2% of the investment costs [2].

Without being involved in the details, it is worth of noting that, when calculating the LEC, beyond the “inner” costs great importance assume the “external” costs, that allow to include also the social and environmental performances of the various sources.

In order to encourage the PV industry to achieve the economies of scale needed to compete, different governments offer financial incentives to electricity consumers to install and operate PV systems. Such policies are implemented to promote national or territorial energy independence, high tech job creation and reduction of carbon dioxide emissions. It should be noted that the European targets for 2020 do not aim only at limiting the gas serra emissions (actually, the relevant effect would be, globally, very limited), but also at pushing a technological replacement of the European firms, allowing them to keep competitiveness in the manufactoring sectors. Indeed, the markets connected with the renewable energy sources will quickly grow for several years, and there are favourable conditions to conciliate research, innovation and trading growth. It is then urgent to favor investments, because without industrial outcomes the European objectives for 2020 would translate in a huge cost.

2 Grid Parity

Subsidies are really boosting the whole PV sector, speeding up the technological evolution and attracting investments from big utilities. Until today the PV market has exhibited a quite constant evolution, so that it is often compared to the sector of microelectronics, governed by the Moore’s law. The “PV Moore’s law” postulates a 20% PV costs reduction with every doubling of cumulative production capacity. Actually, the prices of PV devices reduce by about 8% each year, therefore are halved in about eight years.

The increased availability on the market of solar-grade silicon, that is expected to be adequate for a quickly increasing world demand, contributes to reducing the costs of PV devices. Further important contributes are also expected, in the short-period, by the optimization of the productive processes and, in a longer period, by developments and innovation of PV technologies and materials (see section 8).

Achievement of the “grid parity” will be a milestone for the future penetration of PV in the generation mix. Grid parity should be intended as the equality of the PV LEC and the electricity price at the low-voltage level (clearly, this is very different from the equality of PV and fossil-fueled power plants LECs).

The grid parity achievement, after which PV energy will no longer need financial support by governments, will depend on the reduction of PV costs but also on the conventional energy cost, linked to the oil price: an increasing oil price will favor the competitiveness of energy sources that today are not competitive. The US DOE (Department Of Energy) believes that the grid parity will be achieved by 2015 [3]. The same forecast comes from a recent McKinsey&Co. study [4] and from the Italian PV summit held in Verona (Italy) in May 2009. Italy, California and Japan are today the most accredited States to achieve first the grid parity.

The roadmap towards the grid parity provides for a drastic cost reduction of PV technology and devices, PV cells and modules efficiency improvements, and an average global growth rate of 25-30% in the next years. If these items hold, the growth of PV generation in 2020 can be really surprising, compared with the present share of PV in the generation mix.

3 The current PV market

The today PV market deployment is, to a large extent, dependent on the political framework of any given country. Support mechanisms are defined in national laws. The introduction, modification or fading out of such support schemes can have profound consequences on PV industries.

In 2008, the global PV market reached 5.6 GW and the cumulative power installed totalled almost 15 GW [5]. Spain had an impressive exploit and represented almost half of the new installations with about 2.5 GW of new capacity, driven by the regulation adopted that favored the installation of large PV parks. Germany, with 1.5 GW of additional power, remains the world leader. Italy, but also France, Portugal, Belgium and the Czech Republic, made good scores confirming Europe’s global leadership in the deployment of PV energy. Outside Europe, the US confirmed its trend with 342 MW of newly-installed PV systems over the year, followed by the South Korea with 274 MW.

In December 2009, a projection from Solarbuzz points to the PV market reaching 6.37 GW in 2009 (see Fig. 1), spurred by the significant increase in Germany where the new installations should reach 3.2 GW.

Let us consider in some detail the Italian situation. The boosting mechanism adopted in Italy, in force since 13/4/2007, rewards the electric energy produced by PV plants. The highest subsidies are for small plants (<3 kWp) integrated in buildings, in agreement with the forecasts for the 2020 included in the Position Paper on energy of the Italian government [6]. Since the current strong boosting mechanism is not sustainable for a long time, regulation set a 1200 MW limit for the total power that can be subsidized. The limit should be reached in 2011 and, after then, subsidies will be progressively reduced, as already done in other Countries (Germany, Spain). This regulation caused a sharp growth of PV installations, with 338 MW in 2008 and 342 MW in 2009 (Fig. 2), leading the cumulative power at the end of 2009 just over 800 MW [7]. As much significant are the effects of investments on the various sectors of the PV industry. Despite this boom, however, the share of PV generation is still negligible: 193 GWh (0,065% of the total net generation, equal to 305,5 TWh) in 2008, and about 1000 GWh, (0,3%) in 2009.

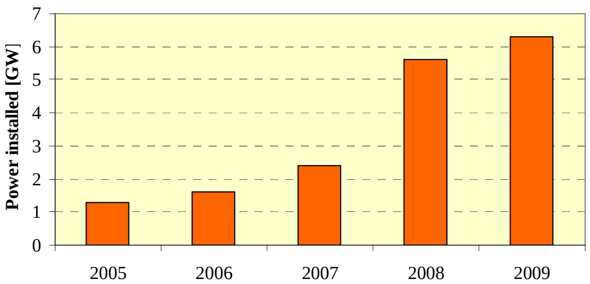

Figure 1. World PV installations (2009: projected value).

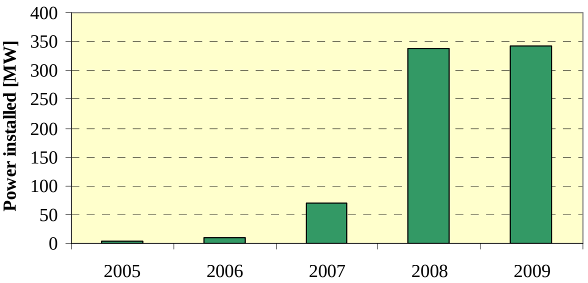

Figure 2. Annual PV installations in Italy.

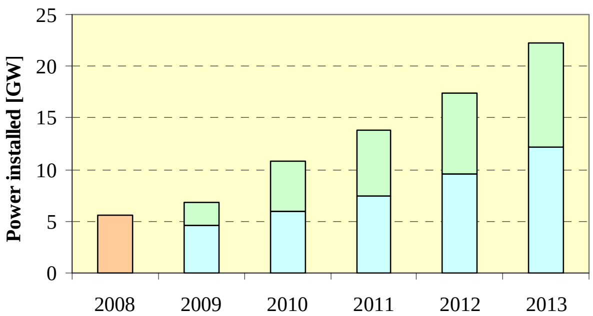

Figure 3. EPIA forecast for global PV installations until 2013: moderate (light blue) and policy-driven (green) scenarios.

4 Forecasts for PV penetration in 2020

A new era for solar power is approaching. How much PV could grow in the next ten years? PV market forecasts depend on a deep understanding of the political framework. In March 2009, EPIA (European Photovoltaic Industry Association) derived two scenarios for the development of the PV industry until 2013 (Fig. 3). The Moderate scenario is based on the assumption of a 'business as usual' situation which does not assume any major enforcement of existing support mechanisms. The Policy-Driven scenario is based on the assumption of the follow-up and introduction of support mechanisms in a large number of countries [5].

Almost one year later, we can perform a first check of these forecasts. The already reported projection of 6.37 GW for 2009 agrees well with the EPIA forecast, being a little under the 6.8 GW of the Policy-Driven scenario. Concerning Italy, on the contrary, EPIA had projected installations to reach 500 MW in the Policy-Driven scenario and 400 MW in the Moderate scenario, more than the 342 MW actually installed during 2009.

EPIA had foreseen the global market to reach in 2013 about 12 GW under the Moderate scenario, which would mean a Compound Annual Growth Rate (CAGR) of 17% over the period 2008-2013. For the Policy-Driven scenario, the annual market is expected to range about 22 GW with a CAGR of 32%.

In 2020, McKinsey&Co. estimates that the global installed PV capacity could be 20 to 40 times its level today. However, even if all of the forecast growth occurs, PV energy in 2020 will represent only about 3-6% of installed electricity generation capacity, or 1.5-3% of output [4].

Concerning Italy, in September 2007 the Italian government [6] estimated a 8,5 GW maximum theoretical PV potential for 2020 (7,5 GW of PV plants integrated in buildings, and 1 GW of solar parks), with an annual generation of 10,2 TWh (9 TWh e 1,2 TWh, respectively), that means 3% of the current electricity consumption (337,6 TWh in 2008). In addition, the document [6] forecasted 1 GW of solar thermodynamic plants, with an annual generation of 3 TWh.

More optimistically, a recent study (2009) of the Italian PV Firms Group believes possible a cumulated PV power up to 16 GW in Italy in 2020, with a rounded annual production of 20 TWh (corresponding to 6% of the current electricity consumption) [8].

Finally, the study "SET for 2020" published in June 2009, conducted by EPIA with the strategic management consultancy A.T. Kearney, analyzes three scenarios for Europe in 2020, characterized by 4%, 6% and even 12% (with 389 GW installed) PV production [9]. In the latter scenario, defined "a demanding, but achievable and desirable objective", detail studies for individual Countries foresee 55 GW for Italy, with a production of 78 TWh (18% of the 2020 consumption forecast, 23% of the current consumption), and 80 GW for Germany! Besides any other consideration, so high PV powers would certainly require profound changes in power systems, such as transmission system expansion, availability of energy storage systems, application of smart grid concepts, load management (see Section 7).

5 Active surface required

Are these forecasts realistic? As already mentioned, practical limits for exploiting solar energy are given by its low density. Therefore, the first issue concerns the availability of the large active surfaces required to install large PV powers. Roughly speaking, today the overall efficiency of PV plants is little more than 10% and, at our latitudes, 1 kWp requires little less than 10 m^2 of PV modules.

Let us refer to the above reported forecasts for Italy. The 8.5 GW of PV plants estimated by the Italian government would require today an active surface of ~70 km^2. Considering, for the PV plants that will operate in 2020, a higher mean overall efficiency in the range 15-20% [10], the required surface would be close to 50 km^2. About 50 km^2 is also the value provided by a study performed by the Italian national commission for solar energy in 2007 [10], aimed at evaluating the total surface realistically available in Italy for PV "roofs" (without considering ground PV plants and accounting for the surface required by solar-thermal plants).

Under the same assumption for the mean overall efficiency, 16 GW would require little less than 100 km^2. Since most of the PV plants, as already reported, are destined to building integration and, therefore, do not waste land, to find a similar surface might not be an insurmountable obstacle, especially if PV generation becomes economically competitive.

On the contrary, more optimistic forecasts, like the 55 GW considered by the already cited study [9], do not appear realistically sustainable, unless the overall conversion efficiency of PV devices rise to a today fantastic level higher than 50%. But a similar exceptional increase is not reasonably imaginable, at least in the next decade.

6 Investment costs

How much would cost to install the above PV powers? Today in Italy complete PV systems are sold at a price around 4-5 k€/kWp for medium-large size PW plants (≥ 20 kWp), and 5-6 k€/kWp for small plants (< 3 kWp). In Germany, these figures are significantly (about 40%) lower, with the mean values lower than 4 k€/kWp. Solar modules take roughly 60% of total costs.

However, prices are continuously reducing. Considering their expected decrease due to the PV market expansion, and the progressive maturation of PV technologies and production processes, one can assume that in 2015 PV systems will be sold at about 2 k€/kWp.

Aiming at evaluating the global costs for the electric system, one has also to consider the effects of the solar energy low availability, due to weather changes (whereas the night/day discontinuity is already considered since PV generation is destined to cover a fraction of the daily modulated load, not of the base-load). Low availability implies that further, more "reliable" power plants must be used as back-up plants for the low radiation periods, and the relevant costs have to be added to the above evaluation (note that, in case of a future large PV growth, back-up costs could have a not negligible impact also on the PV kWh cost). To this extent, and just for reader's guidance, the following p.u. investment costs can be assumed: less than 0,4 k€/kW for modern combined-cycle power plants, and less than 0,5 k€/kW for modern coal-fired plants, respectively.

The installation in Italy of 16 GW until 2020 could represent a roughly estimated cost of 40 billion euros. Such large amount, however, can be considered not unsustainable, since it would be spread over several years and shared among a great number of investors.

7 Power system constraints

In the actual energy debate, crucial for the future of the world, PV energy and the other renewables are central. But very often this topic is characterized by a strong ideological contrast in which the arguments provided by the opposite sides usually neglect the power system requirements and their effect on the generation mix.

Since the base-load cannot be complied with technologies that cannot assure the required high availability, like PV, for a long time a large part of it will be still complied with fossil fuel plants or nuclear plants. Conversely, PV power will be used to comply with a fraction of the daily modulated-load and, therefore, will not technically compete with the base-load power plants.

Nevertheless, it is reasonable to fear an economic competition between the quickly increasing PV and eolic sources and other energy sources, first of all the nuclear one, because the investments demanded by one of the options will reduce the resources available for the concurrent options. In other words, a decided choice on one side would inevitably imply less resources for the other options.

Several examples support this thesis. Germany and Spain, leader Countries in the field of green energies, have followed with decision this way after having decided a progressive getting out of nuclear. Contrarily, France, which has the highest share in the world of nuclear energy, until today has used little its significant eolic potential. Looking outside Europe, Japan has large nuclear and low green generation, and South Korea, in spite of being between the world top ranked States for PV power installed, has recently approved a new energy plan that provides for suspension of financial incentives to PV and development of nuclear, with the declared aim to generate in 2030 one quarter of its national demand with nuclear plants.

Consider now the requirements for a reliable and safe power system operation. The uncertainty of the solar energy makes PV generation not predictable. A power system can accept only a limited fraction of unpredictably changing power, over which a number of problems connected with the violation of network constraints, transmission stability, and fast power availability from different power plants can arise.

Even if PV, because of its still very limited share in the generation mix, does not yet imply these problems, the German power system has already begun to face them with the wind energy, that today totals a far higher power (several GWs are installed mainly in Northern Germany). Indeed, the high share of wind power was supposed to have a role in the chain of events that led to the large perturbation occurred on November 4^{th}, 2006, that caused the European interconnected power system to split into three sub-systems, risking large blackout.

How much unpredictable changing power a power system can accept? To answer this question, that the progressive growth of PV and eolic power will make more and more important in the next future, several TSOs and research groups are trying to predict the power system performance to fast changing generation powers. The results are not common for all Countries, but depend on the specific characteristics of each power system and territory under consideration.

As a general statement, because of the different location and dispersion over the land of wind farms and PV plants, and since different weather variables (wind, insolation) are involved, in a large power system the combined impact of unforeseen changes of the two sources will be considerably attenuated. Nevertheless, considerable power changes can still be produced.

Again, let us refer to the Italian situation. With 12 GW of wind farms and 8.5 GW of PV plants, that are the potentials evaluated for 2020 by the Italian government [6], power generation changes in the GW range could well be caused by sudden weather changes. The effects on the power system can include:

- need for fast injection of a corresponding back-up power to balance the system;
- wide change of power flows, with possible overloads on different power lines, and relevant fast corrections required by the TSO to avoid protection trips;
- reduction of stability margins.

To keep a correct operation, the following are required:

- availability of quickly modulated generation power;
- proper location over the land of back-up power plants.

Assuming that large summer storms can cause up to 20% reduction of the total PV power, back-up powers of various GWs could be required with large PV (and eolic) power installed. For example, in the case of 55 GWs PV the power reduction could easily exceed 10 GWs without considering wind generation! Even if an adequate back-up power might be available in the whole Italian system, not to violate power system constraints most of this power should be produced in Middle-South Italy, where most PV power should be installed and where the power system is not as robust as in Northern Italy. Safe system operation with high PV and eolic powers can be predicted only by accurate large-scale power system studies, that are not yet available. However, the first rough estimates show that the actual network very probably could not accept 55 GW PV.

In conclusion, if PV (and wind energy) will really grow up with a bullish pace in the next years, the problems connected with the uncertain availability of the two sources will certainly become a strong limiting factor, unless profound structural changes are accomplished in the power systems with costs that, today, can be hardly estimated.

8 A glance at PV technologies

An important approach to improving the economical balance of PV power generation relies upon reduction of the cost-per-unit power of the PV devices. This can be achieved by reducing the device manufacturing cost, as well as by enhancing device efficiency.

Silicon is today, and will expectedly be at least for the next ten years, the dominating material in PV industry. The technology based on crystalline silicon (c-Si), which covers today more than 90% of the market, is very well developed and is approaching maturity from the point of view of performance: the best solar cell ever produced in a laboratory has an efficiency of 24.7% and the best silicon-based industrial solar module reaches 22.7% efficiency, respectively more than 80% and 75% of the theoretical maximum (~30%) [11]. However, c-Si technology alone does not seem able to deliver the needed breakthrough in terms of cost-per-power.

Thin films technologies allow drastic manufacturing cost reduction compared to c-Si technologies, thanks to the minimal thickness (to less than 1 μm) of active material deposited over low cost supports. The main examples of materials currently used for fabricating thin film PV modules are amorphous silicon (a-Si), copper-indium-gallium-selenides or sulfides (CIGSS), and cadmium telluride (CdTe). Although these technologies are already commercially available, they are still far from maturity, as demonstrated by the large gap existing between the maximum theoretical efficiency (about 30% for the materials considered [12]) and current device efficiencies (the best module efficiency is 10.4% for a-Si using a “tandem” approach, 13.4% for CIGSS, 10.7% for CdTe, whereas the best laboratory cells reach 18.8% for CIGSS [11]). Clearly, a lot of work can still be done to enhance performance and to optimize fabrication processes. Thin films technologies are expected to reach a 25% share of the PV market around 2013 [5].

Very promising are the multijunction technologies, developed to improve efficiency. Multijunction cells consist of multiple thin films of different semiconductors (for example, “tandem” arrangements with μc-Si e c-Si). Each semiconductor has a characteristic band gap energy which causes it to absorb electromagnetic radiation over a portion of the spectrum. Semiconductors are carefully chosen to absorb nearly all of the solar spectrum, thus generating electricity from as much of the solar energy as possible. In this way, the maximum theoretical efficiency is drastically improved, making a 35% conversion efficiency a realistic objective.

Further improvements could be obtained through sun light concentration on multijunction cells. The laboratory record recently obtained with concentration technics is 41.1% (with a theoretical limit about 60%).

In a long-term perspective, nanotechnology will probably assume great importance in the PV market. Nanotechnology offers the tools for controlling the structure of materials at the scale where the physical phenomena governing the PV effect take place. The optoelectronic properties of materials can then be engineered, creating materials that absorb the sun radiation better, create more free electrons, or facilitate their extraction to provide electrical power. At the same time, a wide variety of cheap processes for fabricating nanostructured materials is available. Many research groups are attempting to use nanotechnology to fabricate cheap and efficient solar cells, following a broad variety of approaches. One project concerns the development of an Intermediate Electronic Band (IB) material [13]. The electronic properties of an IB material enable very efficient absorption of the solar spectrum, strongly enhancing the efficiency potential (from around 30% for a single junction device based on a common semiconductor to 63.5% for single junction device based on an IB semiconductor). The architecture of the final PV device will replicate the one of all devices based on thin films. Commercial modules based on such technology could be realized within five years.

9 Conclusion

The whole PV sector is approaching a more mature stage. PV energy is still too costly, but competitiveness with the electricity price for the end customers could be achived in few years. Nevertheless, it would be wrong to foresee a large PV share in the generation mix, at least for the next 20 years: solar power can certainly help to satisfy the desire for more electricity and lower carbon emissions, but it is just one piece of the puzzle.

The principal limits for the PV generation growth will be the large surfaces requested by the solar energy low density (this limit would become less stringent only in case of really exceptional conversion efficiency increase), and most of all the constraints set by the need for realiable and safe power system operation. These constraints, that soon will have to be clearly individuated through specific studies involving also wind generation, could be mitigated only introducing profound changes in the structure of power systems.

On the contrary, the costs involved in the PV growth will be certainly high, but not unrealistic.

A reasonable forecast for PV generation in 2020, consistent with the above limits, and provided that the current PV LEC will be halved in 4-5 years, could be in the range of 2-3% of the global electricity consumption.

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